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A DESIGN GUIDE FOR DAMPING OF AEROSPACE STRUCTURES

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ABSTRACT

The effectiveness of polymeric damping materials in controlling resonant vibration problems has been established through many successful applications. The area of these applications range from aircraft structures to jet engine structures. An effort is underway to develop a viscoelastic damping design guide for use by designers. This paper provides a brief outline of this effort.

1. INTRODUCTION

Aerospace structures and equipment mounted in these structures are required to operate under a wide range of dynamic loads. When structural resonances are excited, the dynamic loads can produce excessive vibration levels in the structures and equipment. These vibration levels can be significantly reduced by increasing the damping in the dominant modes through the application of viscoelastic damping technology.

The above vibration problems are often encountered following some initial in-service exposure. The high cost of subsequent structural changes has made the application of viscoelastic damping technology both attractive and cost-effective in solving these problems. In many instances the reduction in resonant vibration response has been quite dramatic (Figure 1), exceeding that possible with stiffening for the same weight increment [1]. The need for greater accuracy and reliability has extended the application of this technology to guidance systems, optical systems, and circuit boards to name a few. It has been used to reduce the vibration in stiffened aircraft structures and jet engine parts, the cabin noise in the aircraft, the noise emitted by diesel engines, and the noise transmission in buildings. The use of viscoelastic (passive) damping is also expected to increase in space applications, in conjunction with active damping, since the inherent damping is very low in aerospace metals and high modulus graphite/epoxy composites. These latter materials are being used in increasing quantities in space structures.

Vibration testing and data analysis capability has increased dramatically in recent years. The resonant frequencies and damping in structures can now be determined much quicker and with a greater accuracy. The dynamic loads and vibration environments encountered by aerospace structures and equipment are reasonably well known. Damping materials covering a temperature range from -65°F to 1500°F have been developed. The theory [2,3] for simultaneously curve fitting the measured modulus and loss factor for improved accuracy and consistency has been developed for these materials. The basic Ross-Kerwin-Ungar [4] analysis methods for application of viscoelastic damping to beams

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and plates and the subsequent work by many authors [5,6] have been complimented by the development of finite element methods [7,8] which enable the damping technology to be applied to more complex structural designs. Many successful applications of the viscoelastic damping technology have been reported in the literature. Consequently, it should be possible to anticipate resonant vibration problems and apply the damping technology at the design stage. This approach would not only reduce the cost relative to a subsequent design change, but could also result in a lighter design (Figure 1). This need is becoming more evident as limits of current technology are being approached.

To fully capitalize on this viscoelastic damping technology, it is first necessary to bring all of the pertinent information together in a damping design guide. For a wide appeal, the design guide must be suitable for use by designers. This paper provides a brief outline of such a program, performed in three phases, over a period of 34 months. The program will be completed in July 1984.

2. TECHNOLOGY SURVEY

A technological survey was conducted, primarily in the United States, to identify the aerospace companies, government agencies, research institutes, and individuals active in the field of viscoelastic damping technology. A questionnaire was developed to identify the scope of this activity. An eighteen percent response was obtained to the mailed questionnaires. The results indicate a wide field of application (Figure 2) for the damping technology, primarily for vibration control, followed closely by noise control and fatigue suppression (Figure 3). The data in these figures have not been normalized since many of the respondents were involved in more than one field of activity. The classifications of the individuals involved in this activity is indicated in Figure 4. The research and development (R&D) and the management columns combined represent 93 percent of the individuals active in the field. Consequently, most of the design and production activity is also being supported by the R&D engineers. This result indicates a need for greater dissemination of the damping technology, a primary objective of the damping design guide.

3. DAMPING DESIGN GUIDE FORMAT

The damping design guide has been organized into three volumes.

Volume 1 is intended to be a reference volume summarizing the work performed to date on the application of damping technology and the allied fields. It also contains a bibliography of the published articles in these fields and an assessment of future needs.

Volume 2 is intended to be the user oriented design guide. This volume contains a brief introduction to vibration and damping, and a general discussion on how to identify potential vibration problems and how to select the appropriate damping treatment. One chapter will feature design equations/nomograms for predicting the dynamic response of common structural members, both with and without damping treatment. This will be followed by a

chapter on worked examples based on successful applications of damping technology. The worked examples are divided into the major fields of application, each introduced by a summary of the problems encountered in that field and followed by a single example for each type of problem.

All of the worked examples and analysis methods have been obtained from literature. The worked examples include a comparison of predicted and measured results such as illustrated in Figures 5 to 7 for circuit boards [9], bolts [10] and exhaust ducts [11], respectively, to name a few. Finite element methods, and results of finite element analysis, involving application of damping, are also included. A typical finite element model of a turbine blade [12] damped with a surface glass treatment is illustrated in Figure 8. A total of 234 elements were used to define the damped blade. The cross-section of the blade (Figure 8b) consisted of fifteen elements for the blade and twelve elements each for the nickel and glass layers. The analysis was performed at temperatures of 800, 925 and 1000° Fahrenheit (427, 296 and 538° Centigrade). The peak damping was obtained at the temperature of 925°F (see Figure 9) in the first mode.

This volume also contains a brief summary of other case histories available in literature for which complete information is not available. The purpose is to broaden the scope of application beyond the worked examples. Measured damping levels in typical aerospace structures and materials are included for use in the analysis when measured damping data on the actual structures are not available.

Volume 3 contains the damping material data required by the designer. The damping material modulus and loss factor are presented in the form of the reduced temperature nomogram [13] (See Figure 10) which is accompanied by a data sheet, Table 1, containing other pertinent information. The use of this standardized data format is explained in the introduction of this volume. The organizations from which these damping materials can be obtained are also listed in this volume.

The damping application can be designed using Volumes 2 and 3. These volumes are intended for use in loose-leaf binders to permit updating of the design methods, in light of experience gained, and of the damping materials which are subjected to change from the normal market pressures.

4. CONCLUSIONS

A design guide is being developed to encourage and permit the application of viscoelastic damping technology at the design stage. It is recognized that the designers will require assistance from dynamicists in the initial use of Volumes 2 and 3 of the design guide until they become familiar with dynamics and viscoelastic damping. They will also require help with finite element analysis, dynamic loads/vibration levels/test specifications, and test methods/data analyses required to verify the performance of the damping treatments, which are usually the responsibility of the dynamics engineer. The widespread use of this relatively specialized, but essential technology is, therefore, dependent upon the assimulation of this technology by dynamics engineers outside the R&D classification. The damping design guide, it is hoped, will speed up this process.

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12. Same as Ref 7.

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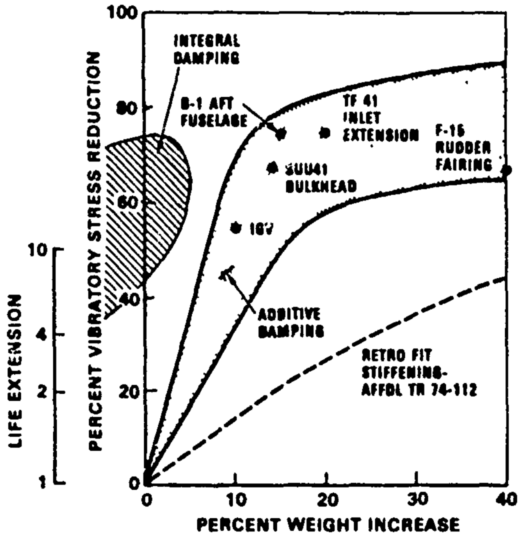


FIG. 1 LIFE EXTENSION OBTAINED WITH ADDITIVE DAMPING ON EXISTING HARDWARE

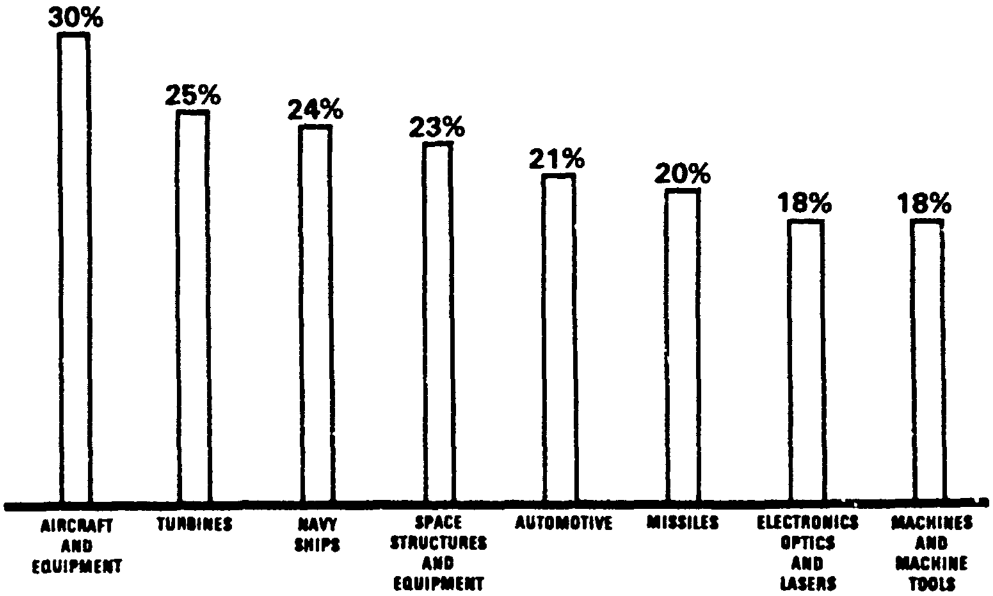


FIG. 2 APPLICATION OF DAMPING TECHNOLOGY

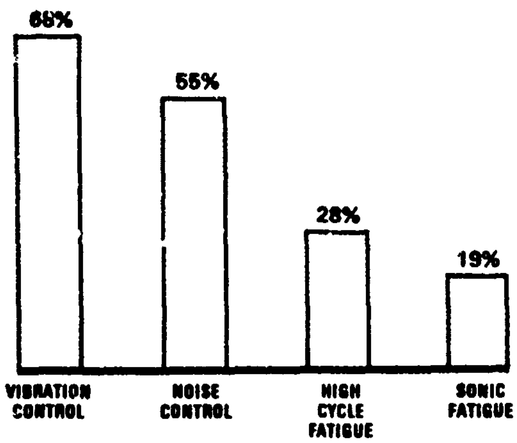


FIG. 3 PURPOSE FOR USE OF DAMPING TECHNOLOGY

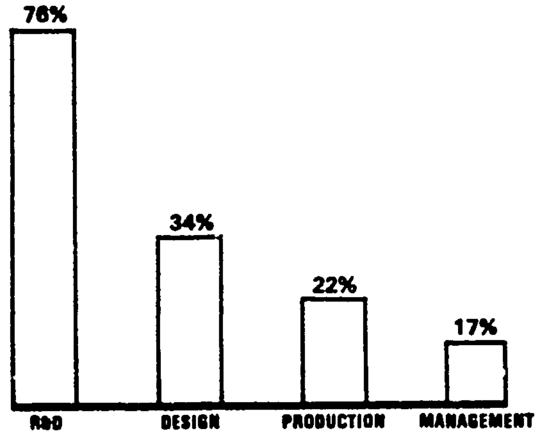


FIG. 4 CLASSIFICATION OF INDIVIDUALS ACTIVE IN THE APPLICATION OF DAMPING TECHNOLOGY

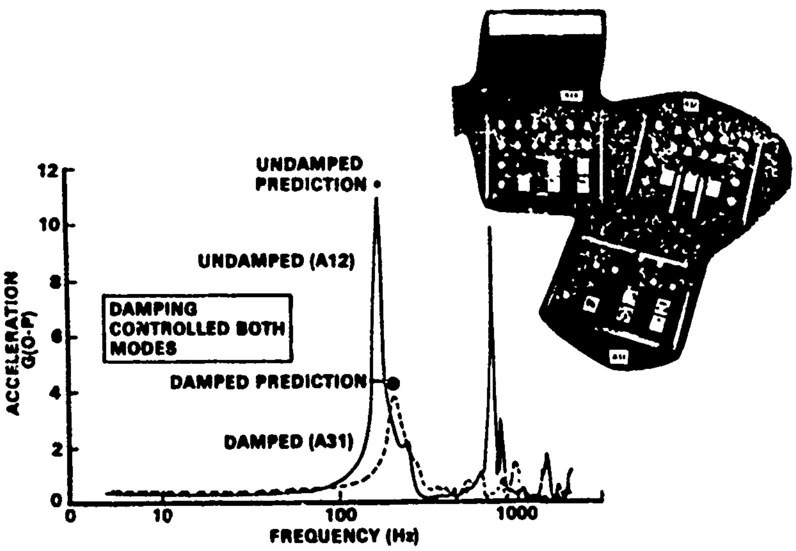
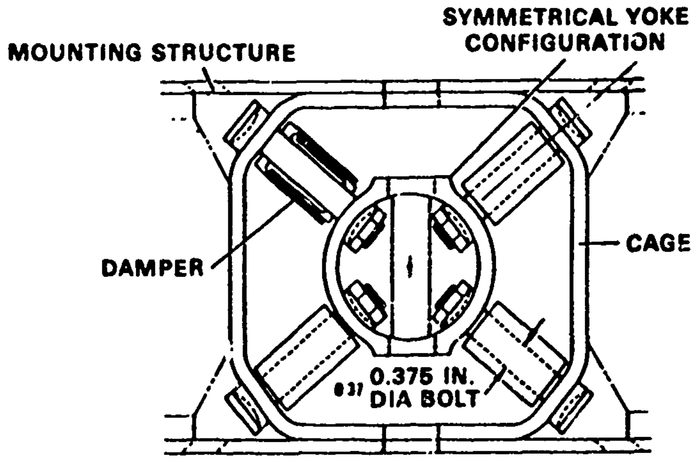


FIG. 5 REDUCTION IN CIRCUIT BOARD VIBRATION WITH ADDITIVE DAMPING



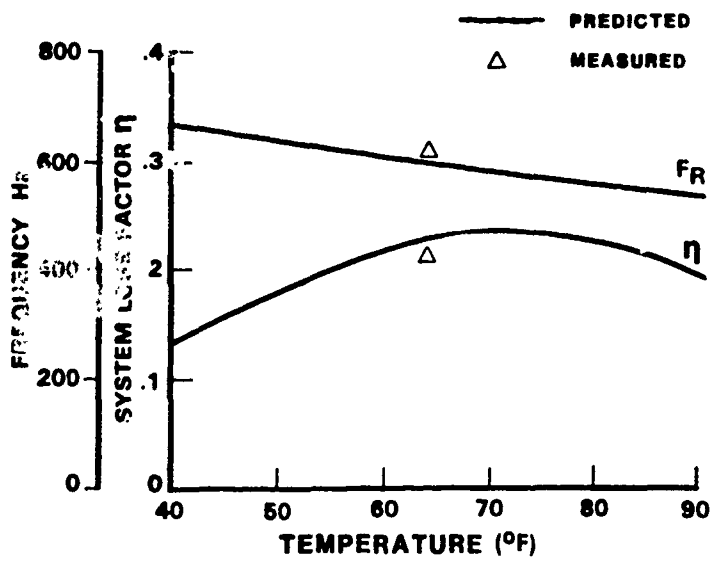


FIG. 6 INCREASE IN LOSS FACTOR OBTAINED WITH DAMPED BOLTS

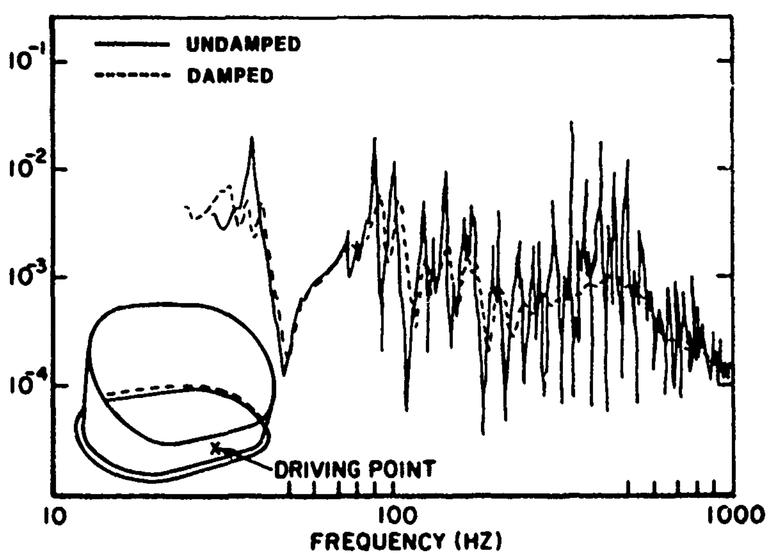
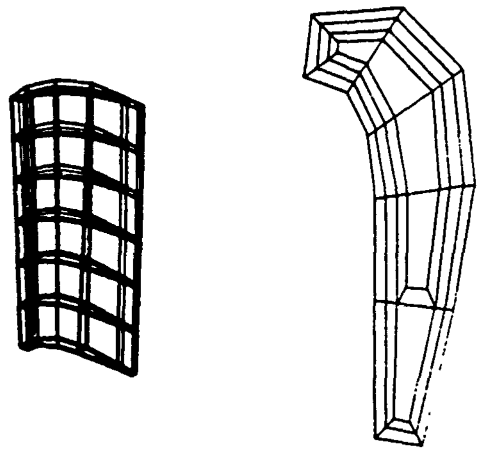


FIG. 7 EFFECT OF DAMPING ON HELICOPTER EXHAUST DUCT VIBRATION



(a) (b)

FIG. 8 FINITE ELEMENT MODEL OF TURBINE BLADE

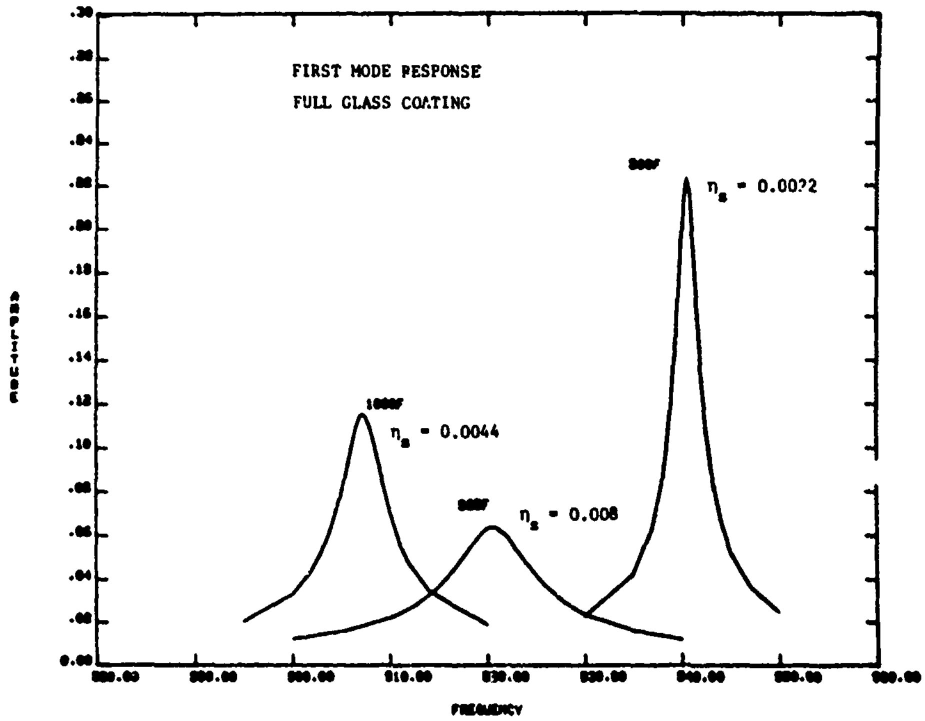


FIG. 9 FIRST MODE BLADE RESPONSE WITH FULL GLASS COATING AT THREE TEMPERATURES

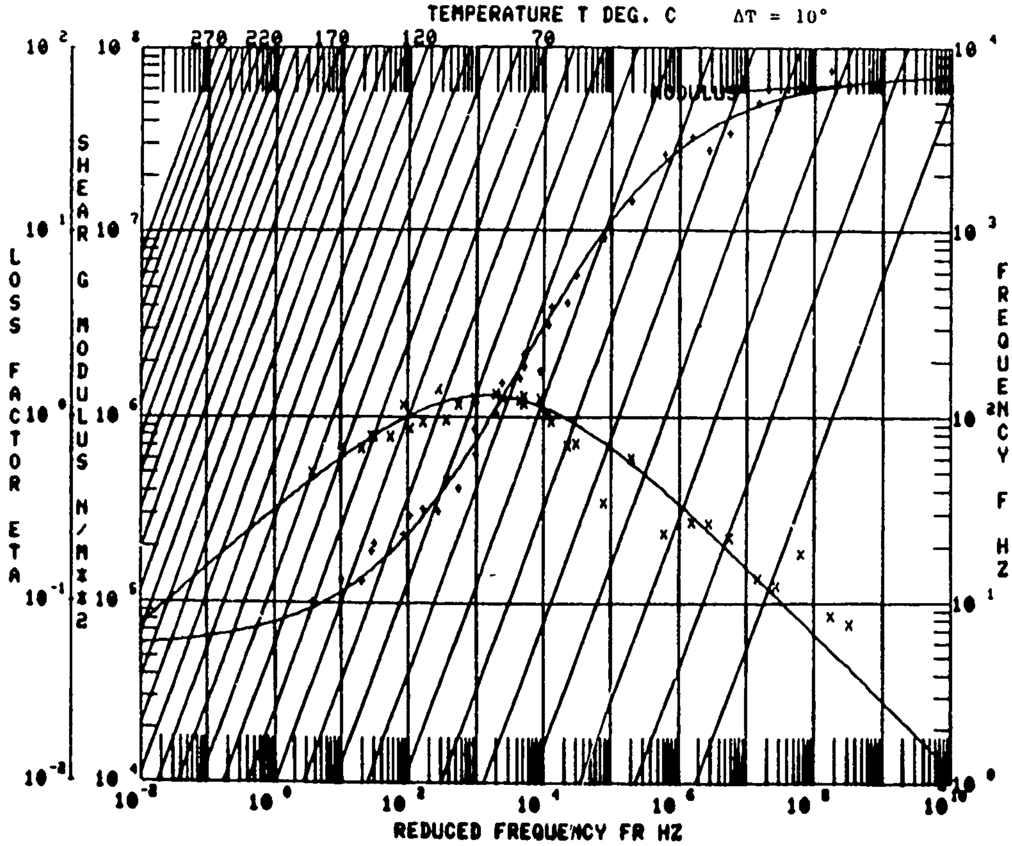


FIG. 10 TYPICAL REDUCED FREQUENCY DAMPING MATERIAL NOMOGRAM

TABLE 1 TYPICAL DAMPING MATERIAL DATA SHEET

MATERIAL MN MANUFACTURER THE SOUNDCOAT COMPANY
MAX LOSS FACTOR η_p 2 1494 MODULUS ■ SHEAR □ YOUNG S
MODULUS AT η_p 06 PSI 4 13E2 PASCALS
MAX MODULUS 1 94E6 PSI 1 34E9 PASCALS
MIN MODULUS 3 77 PSI 2 6E4 PASCALS
MAX SURVIVAL TEMP LONG TERM NA °F °C
MAX SURVIVAL TEMP SHORT TERM NA °F °C FOR MINUTES
ULTIMATE TENSILE STRENGTH NA PSI PASCALS
DENSITY 030 LBS/IN^3 0 83 G/CC
POISSON S RATIO NA
MAX ALLOWABLE STRAIN LEVEL NA
EFFECTS OF CONTAMINANTS NA
EFFECTS OF RADIATION NA
OUTGASSING NA
THERMAL CONDUCTIVITY NA BTU IN/FT^2 HR °F KCAL/SEC METER °C
CONFORMABILITY EXCELLENT
SUPPLIED AS (FORM) AVAILABLE AS SOUNDFOIL - DAMPING MATERIAL WITH ALUMINUM CONSTRAINING LAYER
BONDING AND/OR APPLICATION PROCEDURE MN IS SELF-ADHESIVE AT ROOM TEMPERATURE CLEAN SURFACES TO BE BONDED WITH SOLVENT AND APPLY WITH MODERATE PRESSURE

FREQ. Hz	TEMP FOR η_p °F °C	LOWER LIMIT FOR $\eta \geq 70\%$ η_p °F °C	UPPER LIMIT FOR $\eta \geq 70\%$ η_p °F, °C	MODULUS AT LOWER LIMIT PSI Pa	MODULUS AT UPPER LIMIT PSI Pa
10	-21 -29 4	-48 -43 3	10 -12 2	1 80E3 1 241E7	8 7E1 6 0E5
100	13 -10 6	-15 -26 1	51 10 6	1 82E3 1 255E7	8 4E1 5 79E5
1000	54 12 2	21 -6 1	99 37 2	1 83E3 1 262E7	8 4E1 5 79E5

TEST NUMBER 81 01
T_O 10 °C -12 2

MODULUS CURVE PARAMETERS
FROM 2 0E3
MROM 5 9E6
N 0 3
ML 2 6E4

LOSS FACTOR CURVE PARAMETERS
ETAFROL 2 1
SL 0 4
SH -0 6
FROL 1 3E3
C 1 0

ADDITIONAL COMMENTS